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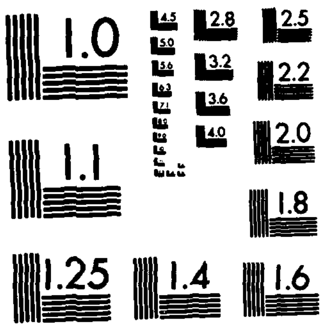

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OPTIMAL SHIP ROUTING AND PERSONNEL ASSIGNMENT FOR NAVAL RECRUITMENT IN THAILAND

BY

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Two problems related to the Royal Thai Navy's recruitment effort are modeled and solved by mathematical programming, The first problem is the optimal assignment of draftees to branch naval bases, which is formulated as a transportation problem. The second problem is the optimal routing of ships for transporting draftees from the branch bases to the main base, which is solved with an exact integer programming formulation.

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OPTIMAL SHIP ROUTING AND PERSONNEL ASSIGNMENT FOR NAVAL RECRUITMENT IN THAILAND

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Abstract

Two problems related to the Royal Thai Navy's recruitment effort are modeled and solved by mathematical programming. The first problem is the optimal assignment of draftees to branch naval bases, which is formulated as a transportation problem. The second problem is the optimal routing of ships for transporting draftees from the branch bases to the main base, which is solved with an exact integer programming formulation.

Introduction

There is compulsory military service for men in Thailand. Inductions take place four times a year, with the men who live in the coastal provinces assigned to the Navy.

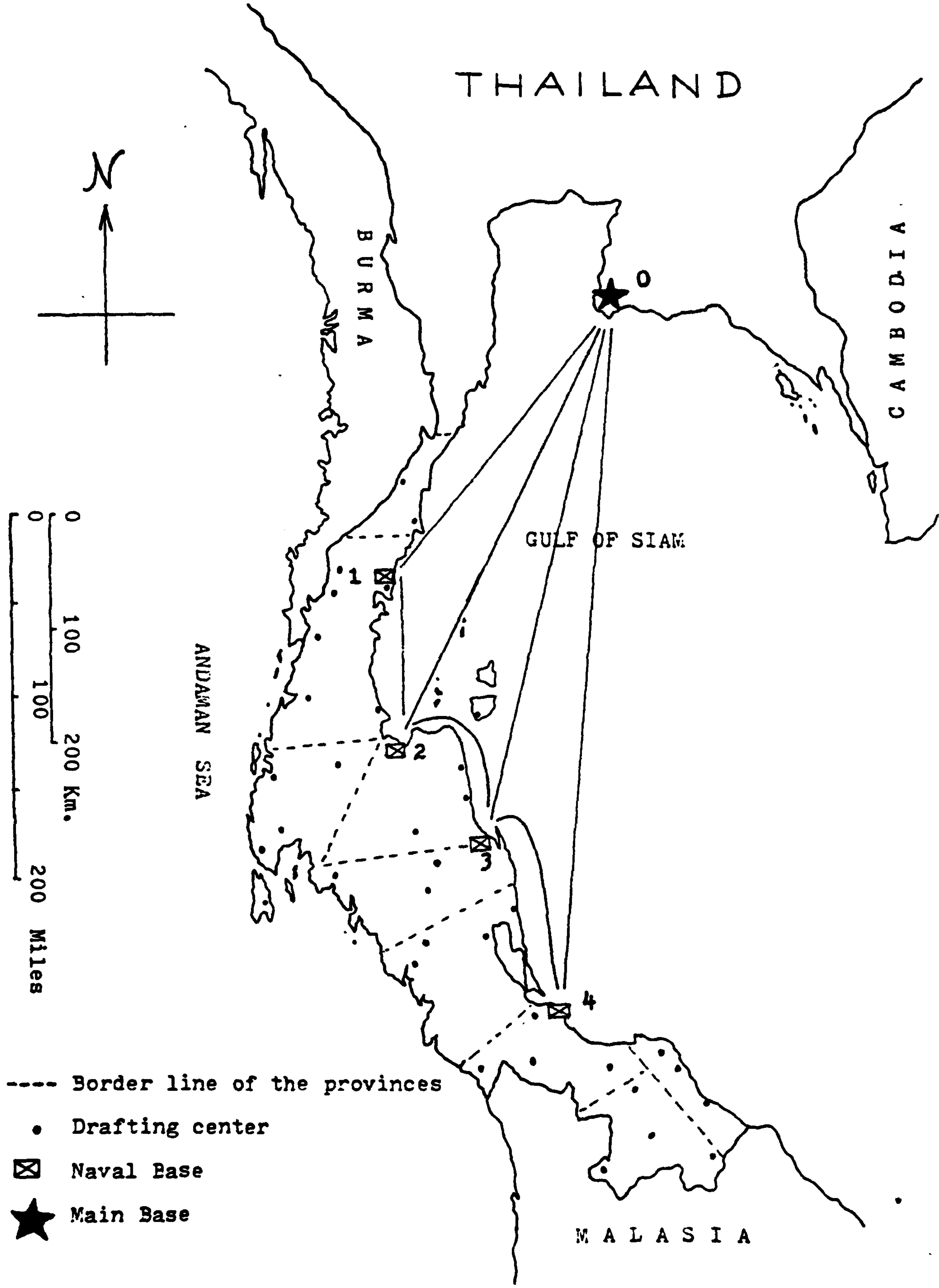
When a man is called into the Thai Navy, he first reports to a drafting center in his home locality. He is then transported by land vehicle to a naval base. If he is from a northern province, this base is the main naval base in Sataheep, near Bangkok. If he is from a southern province, the draftee is first brought overland to a branch naval base and then transported by ship to the main base. (See the map of Figure 1.) In the southern provinces there are 36 drafting centers and 4 branch bases. This paper addresses two problems relating to the assignment and transportation of draftees from the southern provinces:

Problem 1: How many men from each drafting center should be assigned and transported to each branch base?

Problem 2: Given an available fleet of ships stationed at the main base, which of those ships should be used and how should they be routed so as to pick up all the men at the branch bases and transport them to the main base?

The second problem is the more difficult.

We shall present a linear programming model which is used for solving the first problem and an integer programming model which is used for solving the second. The two problems are not independent because the solution to Problem 1 determines the transport requirements for Problem 2.


THAILAND
BURMA
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0
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1
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ANDAMAN SEA
0 100 200 Km.
0 100 200 Miles
MALASIA
---- Border line of the provinces
• Drafting center
Naval Base
Main Base

FIGURE 1

Although it would be possible to build a unified model to solve both problems simultaneously, this would be inappropriate under the Thai Navy's current organizational structure. The personnel decisions of Problem 1 and the ship routing decisions of Problem 2 are made by different people in different places at different times.

Problem 1: Assigning Draftees to Branch Bases

Problem 1 is modeled as a standard transportation problem.

We are given:

b_j = the number of men to be transported from drafting center j,

a_i = the capacity (number of men) of branch base i,

c_{ij} = cost per man for transport to base i from center j,

and we must determine

x_{ij} = the number of men to be transported to base i from center j.

The model is

$$\min \sum_{ij} c_{ij} x_{ij}$$

s.t.

$$\sum_{j} x_{ij} < a_i, \text{ all } i$$

$$\sum_{i} x_{ij} = b_j, \text{ all } j$$

with all $x_{ij} > o$. The vehicles used for transporting the men are sufficiently small so that it is not necessary to use a more elaborate model (e.g, a fixed-charge transportation model) for Problem 1. The results of Problem 1 which are inputs to Problem 2 are

$$d_i = \sum_{j} x_{ij}$$

which is the number of men assigned to branch base i. The data and numerical results for a specific instance of Problem 1 (Summer, 1983) are given in Tables 1 and 2.

TABLE 1. DATA FOR TRANSPORTATION PROBLEM

Drafting Center	Distances to Branch Bases				Number of Men at Center
	B1	B2	B3	B4	
PC	25	100	170	270	98
KR	30	85	165	260	82
PN	10	87	150	250	123
SW	23	77	140	240	54
RN	50	75	150	240	118
CY	77	20	90	180	98
TK	112	29	87	175	73
TP	130	70	120	200	66
BD	100	0	75	170	102
SC	125	50	40	140	57
TS	130	60	23	125	61
PG	160	77	112	175	104
KL	170	90	120	178	60
TL	180	110	120	170	58
PK	195	120	125	70	98
KB	175	82	80	138	107
CW	150	50	28	123	92
TG	170	75	25	100	107
RB	175	80	20	87	93
KM	180	80	48	85	62
RT	210	125	73	50	69
PL	215	125	70	50	88
TR	210	120	75	77	93
KT	220	127	82	78	86
SN	227	135	74	28	74
HY	267	175	110	12	103
PR	260	167	112	70	52
ST	282	185	132	55	77
TA	282	208	133	37	59
SD	280	190	130	31	68
PT	302	220	150	60	83
YR	310	228	162	73	61
SB	325	235	175	81	82
NW	348	270	200	107	96
YL	325	230	168	70	72
BT	360	275	203	100	53
Base Capacities	1000	1100	1300	1500	

TABLE 2. OPTIMAL SOLUTION FOR TRANSPORTATION PROBLEM

From	To	Number of Men	Cost/Man	Extension
PC	B1	98	25	2450
KR	B1	82	30	2460
PN	B1	123	10	1230
SW	B1	54	23	1242
RN	B1	118	50	5900
CY	B2	98	20	1960
TK	B2	73	29	2117
TP	B2	66	70	4620
BD	B2	102	0	0
PG	B2	104	77	8008
KL	B2	60	90	5400
TL	B2	58	110	6380
PK	B2	98	120	11760
SC	B3	57	40	2280
TS	B3	61	23	1403
KB	B3	107	80	8560
OW	B3	92	28	2576
TG	B3	107	25	2675
Re	B3	93	20	1860
KM	B3	62	48	2976
TR	B3	93	75	6975
RT	B4	69	50	3450
PL	B4	88	50	4400
KT	B4	86	78	6708
SN	B4	74	28	2072
HY	B4	103	12	1236
PR	B4	52	70	3640
ST	B4	77	55	4235
TA	B4	59	37	2183
SD	B4	68	31	2108
PT	B4	83	60	4980
YR	B4	61	73	4453
SB	B4	82	81	6642
NW	B4	96	107	10272
YL	B4	72	70	5040
BT	B4	53	100	5300

Total Cost = 149,551

Base	Number of Men Assigned
B1	475
B2	659
B3	672
B4	1123

Problem 2: Routing Ships for Transporting Draftees to the Main Base

The problem of optimally deploying the available fleet of ships to transport draftees to the main base is a type of vehicle routing problem. There is a large number of available approaches to these problems. (See, e.g., Bell et. al. [1983] and Bodin et. al. [1983]). The model given below is related to the set-partitioning approach, in that we first create a list of possible routes that ships can take and then model the problem in terms of variables representing the number of times each route is used. Since ships are not identical, these variables must also denote which type of ship is chosen.

In most vehicle routing problems, the objective function is the total distance traveled or some concomitant cost measure. The Thai Navy's situatior different. Their primary objective is to minimize the number of ships req ed for transporting all the draftees. This is because defending the country, transporting draftees, is the principal mission of the Navy fleet. As few vessels as possible should be assigned to this duty, so that the remaining ships can be available for defense. Since we anticipate that numerous solutions would alternatively optimize this primary objective, we use distance minimization as a secondary, tie-breaking objective.

The fleet available for draftee transport at the time of this study consisted of 9 vessels of 3 different classes. This fleet is described in Table 3.

TABLE 3. FLEET DESCRIPTION

Class of Ship	Capacity of Ship (Number of Men)	Number of Ships in Class	Bases that Class Can Visit
1	100	2	1
2	200	3	1, 2, 3
3	600	4	1, 2, 3, 4

From this information we generated 23 possible voyages for the model to consider using. A voyage is defined as a particular class of ship assigned to sail a particular route. The 23 voyages are described in Table 4. Node 0 in the route specifications means the main base.

TABLE 4. VOYAGE SPECIFICATION

Voyage	Class	Route	Distance (km)	Capacity (men)
1	1	0-1-0	370	100
2	2	0-1-0	370	200
3	2	0-2-0	460	200
4	2	0-3-0	600	200
5	2	0-1-2-0	515	200
6	2	0-1-3-0	640	200
7	2	0-2-3-0	665	200
8	2	0-1-2-3-0	720	200
9	3	0-1-0	370	600
10	3	0-2-0	460	600
11	3	0-3-0	600	600
12	3	0-4-0	750	600
13	3	0-1-2-0	515	600
14	3	0-1-3-0	640	600
15	3	0-1-4-0	810	600
16	3	0-2-3-0	665	600
17	3	0-2-4-0	805	600
18	3	0-3-4-0	800	600
19	3	0-1-2-3-0	720	600
20	3	0-1-2-4-0	860	600
21	3	0-1-3-4-0	840	600
22	3	0-2-3-4-0	865	600
23	3	0-1-2-3-4-0	920	600

The method used for generating the set of available voyages is the following. For each ship class, we enumerate every subset of bases that can be visited on a voyage and then we compute the shortest route for that subset. All voyages worth considering are thereby generated. If the ship routing problem were posed by another fleet whose number of classes and number of bases were much greater than the Thai's, then this exact approach might become computationally infeasible.

The variables in our integer programming model for Problem 2 are:

z_j = number of times voyage j is used, and

y_{ij} = number of men transported from base i to the main base via voyage j.

The data for the integer programming model are:

V_i = set of voyages that visit base i,

S_k = set of voyages that use a ship of class k,

B_j = set of bases visited on voyage j,

d_i = number of men to be transported from base i,

n_k = number of ships available of class k,

c_j = capacity of voyage j, and

r_j = distance traveled by voyage j in tens of thousands of kilometers.

The model is

$$\min \sum_j (1 + r_j) z_j$$
s.t.

$$\sum_{j \varepsilon V_i} y_{ij} = d_i, \quad \text{all } i$$

$$\sum_{i \varepsilon B_j} y_{ij} < c_j z_j, \quad \text{all } j$$

$$\sum_{j \varepsilon S_k} z_j < n_k, \quad \text{all } k$$

$$z_j > 0 \text{ and integer}$$

$$y_{ij} > 0.$$

The objective function, as noted, primarily serves to minimize the number of voyages required. The r_j have small values and serve only to break ties. The first constraint set insures that all the drafted men at base i are transported, using voyages that in fact pass trough base i. The second constraint set insures that the number of men transported via voyages of

type j is within the capacity that will be made available. The third constraint set insures that each ship in the fleet is used at most once. A ship can not be reused because all the draftees have to start their training at the main base at the same time.

Software Employed

The transportation model of Problem 1 is of course a standard problem for which numerous effective packages exist. In our case we used GNET, the capacitated transshipment problem solver of Bradley, Brown and Graves [1977]. We wrote a problem generator and report writer in FORTRAN to use in conjunction with this program, and we used the DEC-10 computer's TOPS-10 operating system for managing the necessary file interfaces.

The integer programming model in the particular instance we solved was small enough to handle with the general purpose solver LINDO of Schrage [1981]. The model formulation above for the Thai fleet of Tables 3 and 4 has 23 integer variables z_j and 45 continuous variables y_{ij}. The z_j variables can take on any integer value up to and including the number of ships in the class assigned to voyage j. LINDO, like many other commercial integer programming solvers, requires that all the integer variables be binary. Therefore, we had to reformulate the model with the z_j replaced by the binary expansions:

$$z_j = z_{j1} + 2z_{j2}, \qquad j = 1,\ldots,8,$$

$$z_j = z_{j1} + 2z_{j2} + 4z_{j3}, \quad j = 9,\ldots,23$$

This resulted in a model with 61 binary variables.

Another problem generator was written to automatically generate the voyages and create this input, so that other instances of the model can be treated routinely. The results for the model instance based on Tabls 3 and 4 are given in Tables 5 and 6.

TABLE 5. OPTIMAL SOLUTION TO SHIP ROUTING MODEL

Nonzero Variable	Value	Interpretation
Z(2,2)	1	Use voyage 2 twice.
Z(5,1)	1	Use voyage 5 once.
Z(10,1)	1	Use voyage 10 once.
Z(11,1)	1	Use voyage 11 once.
Z(12,1)	1	Use voyage 12 once.
Z(18,1)	1	Use voyage 18 once.
Y(1,2)	400	Transport 200 men on each voyage 2.
Y(1,5)	75	Transport 75 men from B1 on voyage 5.
Y(2,5)	59	Transport 59 men from B2 on voyage 5.
Y(2,10)	600	Transport 600 men from B2 on voyage 10.
Y(3,11)	595	Transport 595 men from B3 on voyage 11.
Y(3,18)	77	Transport 77 men from B3 on voyage 18.
Y(4,12)	600	Transport 600 men from B4 on voyage 12.
Y(4,18)	523	Transport 523 men from B4 on voyage 18.

TABLE 6. OPTIMAL SHIPPING SCHEDULE

Voyage	Class of Ship	Route	Men Carried	Distance
2	2	0-1-0	200	370
2	2	0-1-0	200	370
5	2	0-1-2-0	75+59	515
10	3	0-2-0	600	460
11	3	0-3-0	595	600
12	3	0-4-0	600	750
18	3	0-3-4-0	77+523	800

Total number of voyages = 7

Total distance = 3865 km

Discussion of Results

According to Thai Naval authorities, the results obtained by the mathematical programming models are superior to the results obtained through the manual procedures currently employed. In the instance of the transpor-tation model reported above, it turned out that just sending each man to the nearest base, as would be done by the manual procedure, turned out to be

feasible. However, in other instances, this procedure has resulted in violations of the base capacities, which necessitated additional transportion of men from oversubscribed bases to undersubscribed bases. The authorities were pleased to see that the cost and time delays of these extra trips could be avoided.

With respect to the ship routing model, again the authorities were pleased to see our recommendation of an efficient deployment of their fleet. Data gathering is currently in process to determine how many voyages and kilometers could have been saved if the mathematical programming models had been available for the past few years.

Conclusion

Two mathematical programming models, a standard transportation model and a new and exact integer programming formulation, have been shown to be effective for optimally routing ships and assigning personnel for Thai Naval recruitment. The models were solved by general purpose software. Our approach is potentially applicable to other situations, however it is likely that special purpose software would be needed for the integer programming problem if larger fleets are considered.

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OPTIMAL SHIP ROUTING AND PERSONNEL ASSIGNMENT FOR NAVAL RECRUITMENT IN THAILAND.

ABSTRACT

(U) TWO PROBLEMS RELATED TO THE ROYAL THAI NAVY'S RECRUITMENT EFFORT ARE MODELED AND SOLVED OF DRAFTEES TO BRANCH NAVA L BASES, WHICH IS FORMULATED AS A TRANSPORTATION PROBLEM. THE SECOND PROBLEM IS THE OPTIMAL ROUTING OF SHIPS FOR TRANSP ORTATING DRAFTEES FROM THE BRANCH BASES TO THE MAIN BASE, WHICH IS SOLVED WITH AN EXACT INTERGER PROGRAMMING FORMULATIO N. (AUTHOR)

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  USE OPTIMIZATION
      ROUTING
      SHIPS

PERSONNEL ASSIGNMENT
  USE BILLETS(PERSONNEL)

TRANSPORTATION PROBLEM
  USE TRANSPORTATION

NAVAL BASES
  USE NAVAL SHORE FACILITIES

OPTIMAL SHIP ROUTING
  USE OPTIMIZATION
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